ADVANCED LIGHT SOURCE STRATEGIC PLAN

Updated May 2006

With the approaching full realization of former Director Chemla's original strategic plan, the Advanced Light Source (ALS) stands at a pivotal point in its history. The emphasis of the new strategic plan outlined below is to keep the ALS at the cutting edge for the next 2–3 decades by the honing of our existing stock and by the creation of sharper tools that exploit the very significant advances in accelerator and insertion-device technology that have occurred since the ALS began operation. The plan dovetails neatly with the scientific priorities of the DOE Office of Basic Energy Sciences. It is also responsive to the needs of our users, not only in the provision of scientific tools, but also in the provision of a safe and supportive research environment

Table of Contents

ADVANCED LIGHT SOURCE STRATEGIC PLAN

1. Strategic Philosophy

The mission of the ALS is to "support users in doing outstanding science in a safe environment." All our strategic planning is done against the background of this overarching goal.

An early outline of our strategic plan was presented as part of the Office of Science Twenty-Year Facilities Roadmap. We proposed an orderly upgrade of the ALS, at modest cost, comprising three components:

- the upgrade of the source,
- the replacement of the older insertion devices,
- the addition of new application-specific beamlines.

The plan has subsequently been fleshed out in a series of workshops and meetings with our user community and with input from our Scientific Advisory Committee.

The ALS is a world-leading facility optimized for spectroscopy and imaging in the ultraviolet and soft x-ray regions of the electromagnetic spectrum. We address many fundamental questions, such as: Where are the electrons? Where are the atoms? Where are the spins? With our superbend beamlines, we are also world-competitive in the hard x-ray region.

A major focus throughout the strategic planning process has been on the qualitatively new science that will be enabled by the upgrade of the source. The challenging areas that can be addressed at the ALS include:

- size-dependent and dimensional-confinement phenomena at the nanoscale,
- correlation and complexity in physical, biological, and environmental systems,
- temporal evolution, assembly, dynamics, and ultrafast phenomena.

These areas dovetail with priorities of the DOE Office of Basic Energy Sciences.

The planning process is ongoing, with workshops, reviews and meetings to validate the scientific need, to organize the teams, and to create detailed designs for each major component of the plan.

We recognize that priorities can change. This updated plan (May 2006) differs in some significant respects from the original plan (March 2005). Our first priority in Wave 1 is still to chicane a straight section and to construct two innovative beamlines (now referred to as COSMIC and MAESTRO). Practical considerations, however, have led us to transfer this development to Sector 7.0 from Sector 12.0. This in turn has required us to abandon the possibility of picosecond crabbing. Our second priority in Wave 1 was to establish a super-bend beamline for small-angle x-ray scattering (SAX) in the hard x-ray region. Consultations with representatives of the Molecular Foundry have indicated a strong preference for SAX in the soft x-ray region using an undulator. The redevelopment of Sector 8.0 has consequently been elevated in priority.

The strategic plan described below is organized into three main sections:

- Current Developments
- New Initiatives
- The Human Dimension

2. What Would the Plan Cost?

Another significant difference with the original plan is that we now present cost estimates for the new initiatives. These are summarized briefly immediately below. A more detailed breakdown can be found in the individual sections. All costs are in FY'06 dollars.

The redevelopment of the straight sections will be carried out in an orderly sequence of modest incremental upgrades. The estimated *totals* of these *incremental* upgrades, by sector, are as follows.

Sector 7.0: $14.2M;
Sector 8.0: $12.1M;
Sector 10.0: $9.5M;
Sector 6.0: $5.0M;
Sector 2.0: $7.3M.

Optics development and upgrade combined are estimated at $2.5M/year. Detector devel opment is estimated at $1.5M/year.

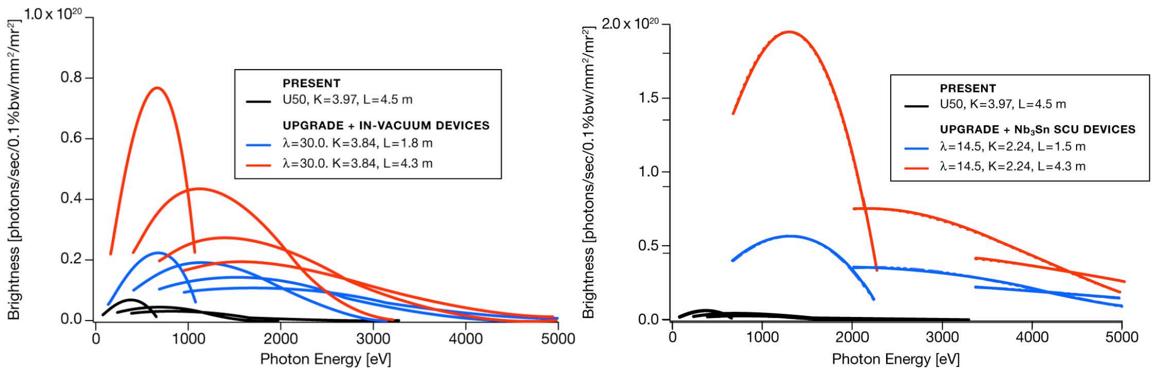
The medium-term initiative, CIRCE (Coherent InfraRed CEnter), is estimated at $38.7M.

CURRENT DEVELOPMENTS

3. Accelerator Upgrades: Top-Off Operation

Our highest priority for upgrade of the accelerator is to establish top-off operation of the storage ring, with 500 mA current. Top-off was pioneered at the APS, with excellent results. Much as in the case of the APS, we expect to benefit from increased time-averaged current (in our case, a 100% increase), and much-improved stability of the beam due to a constant heat load on the accelerator vacuum chamber and, especially, on beamline optics.

Implementing top-off will reap even higher benefits at the ALS than at the APS since, at our lower-energy ring, lifetimes are shorter because of the Touschek effect. To keep the lifetime reasonable in our normal operations, the ALS is running at a considerably lower brightness than its full capability. With top-off, this compromise will no longer be necessary, and the emittance of the beam will decrease fivefold, thus providing an increase in brightness. The improvement in the absolute stability of the beam with top-off becomes even more important for the resulting smaller source size. In addition, we plan to operate with small-gap in-vacuum undulators, further enhancing the brightness, especially in the important energy range above 500 eV.



ALS brightness curves

Concurrent development of $NbSn_3$-based superconducting undulators will extend the reach of ALS undulators, especially in the multi-keV range. The combination of top-off and these new insertion devices will allow us to increase the brightness from 8 to over 100 times, depending on the specific undulators and photon energy in use.

Top-off requires upgrading the booster from 1.5 GeV to 1.9 GeV operations, significant changes to the radiation-protection system, and a variety of other hardware and control improvements. The detailed design was completed and validated by an external review committee in November 2004. The total cost will be $4.85 million. With support from BES, we are starting to procure the long-lead-time components, and we will upgrade to a full-energy injector in a 2006 shutdown. After the shutdown, we will migrate to top-off injection, with higher currents and smaller emittance.

4. Beamlines Under Construction

Currently there are five beamlines under construction, three based on undulator sources, one based on a regular bend magnet, and one on a superbend. Completing these in a timely manner has very high priority.

4.1. PEEM3 (Beamline 11.0.1)

Exciting questions, such as the pinning mechanisms in magnetic domains, can only be answered with extremely-high-resolution instruments. PEEM-3 is the next step in the development of advanced imaging capabilities at the ALS. It will be installed at an undulator beamline designed specifically as a source for an aberration-corrected photoemission electron microscope (PEEM-3). The beam line and undulator (elliptically polarizing type—EPU) are funded by DOE BES at a total cost of $3.7 million. PEEM-3, currently being completed at the ALS, is planned to have a spatial resolution down to a few nanometers. The system will be primarily used for studying magnetic and polymer nanostructures.

4.2. Ultrafast X-Ray Facility (Beamlines 6.0.1 and 6.0.2)

Studying atomic motion at the molecular-vibration timescale requires new tools. Designed to increase the availability of femtosecond x rays at the ALS a thousand-fold, this undulator beamline will be used for x-ray diffraction and spectroscopy with 200-fs time resolution. Ultrafast studies can give rise to a new *Science of Excited States*. One can witness the birth of an elementary excitation. Here is a great opportunity for theory, simulation, and experiment to work in synergy to guide the approach into the future. Funded by BES at a cost of $4.7 million, this beamline is an extension of the laser-driven electron-beam-slicing source currently in use on bend-magnet Beamline 5.3.1. Initially we will have one insertion device feeding two monochromators, one for the soft x-ray region and one for the hard x-ray region. The intent all along has been to install eventually a second insertion device (an EPU) to service the soft x-ray monochromator. The estimated cost of the EPU is $1.0M.

Many of the techniques to be developed on these beamlines will find direct applications in the experimental program at the LCLS.

4.3 MERLIN (Beamline 4.0.1)

Low-energy excitations are crucial to understanding the behavior of strongly correlated systems. Studying these systems requires tools with ultrahigh resolution. MERLIN is an undulator beamline with full polarization control from an EPU in the VUV energy range below 150 eV. It is designed to provide ultrahigh energy resolution for angle-resolved photoemission and inelastic x-ray scattering. It is funded by BES at a cost of $3.5 million.

4.4. Soft X-Ray Microscope XM-2 (Beamline 2.1)

A bend-magnet beamline is being constructed as part of the "National Center for X-Ray Tomography" for high-resolution soft x-ray microscopy and tomography of biological cells. It is funded jointly by the NIH and DOE/BER at a cost of $2.6 million for construction (plus $6.4 million for operations over five years).

4.5. Microdiffraction (Superbend 12.3.2)

Funds have been secured from the NSF to migrate our highly successful microdiffraction program from its bend-magnet beamline (7.3.3) to a new home on a superbend.

NEW INITIATIVES

5. Wave One: Proposed New Beamlines

We plan to exploit the source developments described above to extend experimental capabilities with high spatial and temporal resolution and utilize the remarkable coherence properties of the ALS. Top-off operation will make possible the replacement of our 12-year-old 5m-long undulators with pairs of chicaned 2m-long modern insertion devices with superior performance, feeding a new generation of beamlines to address the outstanding problems of the coming decades. The initiatives outlined below are new. White papers have been written, and proposals for funding are in preparation.

5.1. Coherent Scattering and Diffraction Microscopy (COSMIC) Sector 7.0

As our highest priority in Wave 1 we propose to establish in half of Sector 7.0 a beamline to provide coherent light in the 0.5–2 keV range with full polarization control. The motivation for this initiative has several parts:

.***(a) The quest for nanoscale tomography: Seeing inside structures.*** The ability to image in three-dimensions the internal structure of complex, fine-grained materials at high-spatial resolution is an outstanding challenge with an urgent need in materials science. These materials span the range from labyrinthine, mesoporous catalysts to electronic devices.

.***(b) Seeing inside biological structures.*** The grand challenge of whole-cell imaging at molecular resolution forms the basis of a substantial worldwide research effort. A tomographic single-particle imaging technique that can identify and locate large proteins or macromolecular assemblies of known crystallographic structure within a cell would make an immense contribution. The ALS effort will complement cryo-electron microscopy studies of smaller cells.

.***(c) The time domain is a new frontier.*** The time evolution of mesoscopic systems is crucial to understanding advanced materials and emergent phenomena—there are subtle types of order, i.e., topological order, that are not long-range in nature, but possess fascinating phase transitions nonetheless. Also, the use of soft x rays is an entirely new direction for correlation spectroscopy to study fluctuations in magnetic systems and in soft condensed-matter systems, including biological systems.

One branch of this beamline will serve the soft x-ray coherent scattering community, where much of the interest is in magnetic phenomena. This approach is designed to study time correlation as well as magnetic-field and temperature-dependent correlation and hysteresis phenomena. The other branch will be devoted to diffraction microscopy. This new form of lensless imaging is designed to provide 3D structures to 10-nm resolution for frozen hydrated biological specimens and even higher resolution where radiation damage is not a limitation. This will be a major new venture in the use of soft x rays as a nanoscale probe.

We emphasize that the scientific novelty of this proposed beamline is *coherence based* and is enabled by the top-off and brightness upgrades of the accelerator.

We plan also to augment the COSMIC beamline with an optimized facility for RIXS (Resonant Inelastic X-ray Scattering). This would retain and improve the very active RIXS program already operating in Sector 7.0.

5.2. Microscopy and Electronic Structure Observatory (MAESTRO) Sector 7.0

ARPES at the ALS and elsewhere has emerged as a leading technique for understanding the electronic structure of high-temperature superconductors and other complex oxides. Often, the most interesting materials are intrinsically, or extrinsically, inhomogeneous (i.e., in nanoscale phase segregations). Small probe sizes enable the isolation of more homogeneous, perfect materials than can be achieved by interrogating the entire sample. The quality of the science that can be extracted tends to be directly related to the sample quality. Smaller probe size translates to better science. In some other cases (as with transuranics), larger specimens would pose unacceptable hazards.

Work done by CXRO at the ALS has led to the development of truly remarkable optics. In collaboration with CXRO, we propose to use zone-plate optics to create a 50-nm probe for a nanoARPES facility using the other half of Sector 7.0. This will be a unique capability for the study of surfaces and structures that cannot be prepared in larger formats and for nanostructures created in the Molecular Foundry. NanoARPES will specialize in valence-shell photoemission in the energy range of 20-600eV.

Estimated costs of Sector 7.0 redevelopment in FY2006 dollars;

Undulators and front ends:	4.5M$
COSMIC beamlines	4.8M$
MAESTRO beamlines, prep	4.9M$

5.3. Soft X-ray Scattering in Partnership with the Molecular Foundry Sector 8.0

What are the rules that govern self-organization? This question spans a broad range of topics, from correlated electron systems to protein folding, to surfactant-coated nanoparticle ripening to form monodispersed size distributions and beyond (to the organization of the cosmos). The new materials studied apply to many advanced national missions such as space exploration, the construction of particle accelerators, medical advances, and the U.S. energy problem, which has become a homeland security and environmental issue. The materials that are investigated utilizing the unique capabilities of the ALS are also used to create modern-day computers. A new undulator beamline will be constructed for time-resolved small-angle scattering. This facility will make it possible to follow, in real-time and with elemental discrimination, the synthesis and self-assembly of novel nanostructures. This will facilitate the development of joint programs with the Molecular Foundry, LBNL's Nanoscale Science Research Center (NSRC).

We envision the establishment of two chicaned undulators in Sector 8.0, one to feed the soft x-ray scattering program outlined above, the other to enhance the very productive photon-in/photon-out experimental systems already in place.

Estimated costs of Sector 8.0 redevelopment in FY2006 dollars:

Undulators and front ends:	3.9M$
Soft x-ray scattering beamline & end stn.	4.4M$
Photon-in/photon-out beamline	3.8M$

6. Wave Two: Proposed New Beamlines

6.1. Enhanced VUV Spectroscopy Sector 10.0

We need to keep some of the flagship beamlines, which have been operating for a decade in an ever-more oversubscribed mode, at the cutting edge. The highest priority in Wave 2 is to chicane the Sector 10.0 straight section and give each branch—the condensed-matter-physics photoemission branch (HERS) and the atomic/molecular physics branch—a separate EPU of its own for full polarization control and a separate beamline that can run simultaneously. This beamline has been exceedingly productive in terms of high-profile publications and citations. Each of the new, separate beamlines will be application-specific, optimized for the scientific program of the two user communities, without the need for the compromises of the shared beamline in current use.

Estimated costs of Sector 10.0 in FY'06 dollars including contingency:
Undulators and front ends: 3.9M$
HERS beamline 2.7M$
AMO beamline 2.9M$

6.2. Q-Resolved Inelastic Scattering Beamline, QERLIN Sector 2.0

While the MERLIN beamline is designed for the ultimate energy resolution in the energy range below 150 eV, there is a great need to extend the capability for ultrahigh resolution inelastic x-ray scattering (IXS) investigations to energies at least as high as 1 keV, so as to be able to scan the q-vector out to the Brillouin zone boundary. The ability to map the q-dependent dispersion relations of exotic elementary excitations in complex media is key to understanding many outstanding problems in condensed-matter physics. The elemental, spin, and orbital sensitivity of resonant soft x-ray scattering offers a unique combination of capabilities that will lead to many high-impact experiments. We plan to build on the experience at MERLIN in designing this new facility, which should fit into Sector 2 with a modest rearrangement of accelerator components. This beamline will have to be extra long, and this is the only location at the ALS, where the necessary length is available. The incorporation of very high-resolution photoemission in the 1-keV range would be considered.

Estimated costs of QERLIN in FY'06 dollars including contingency:
Undulator, straight chamber, and front end: 2.5M$
QERLIN beamline & end station. 4.8M$

7. Wave Three: CIRCE, a Dedicated THz Source

In the longer term, we are eager to construct the Terahertz source, CIRCE (Coherent Infrared CEnter).

Two years ago, a national workshop was held on terahertz science and its future. The report on this workshop concludes that, while the community needs to grow and mature, the scientific case for a terahertz user facility will become stronger. The leading candidate for a highly stable source based on coherent synchrotron radiation is CIRCE. This source is designed to make use of the ALS injection system, would sit on top of the booster ring, and would feed an initial complement of eight beamlines. This facility will provide ultrashort pulses and be well suited to a wide variety of pump–probe experiments. The ALS is one of the leading participants in the national THz network that was proposed in the workshop report and has now come into existence.

Estimated cost of CIRCE in FY'06 dollars including contingency: 38.7M$

8. Optics and Detectors

Currently there are 35 beamlines operating at the ALS, including 8 beamlines dedicated to macromolecular crystallography. These form the core resource for the increasing scientific impact and productivity of the facility. While some of the older beamlines will be retired as new, more powerful beamlines come on line, the rest need to be maintained or further improved to reach the state-of-the-art level. This is a highly cost-effective way to keep the facility at the cutting edge.

8.1. Optics

Experimental stations at the ALS depend for world-leading performance on state-of-the-art optical components. Development of zone-plate focusing devices needed by our x-ray microscopists requires advanced lithography support if we are to reach the goal of routine 10nm spatial resolution.

Most beamlines use mirrors and gratings, which, for the preservation of brightness, now demand angular shape errors less than 0.2 microradians and height errors less than a few nanometers. Deterioration of mirror optics due to thermal and ion-induced roughening as well as shape changes due to thermal stress has emerged as a significant problem. The problem will become more severe as we go into top-off operation. We therefore need to replace many of the beamline optical components around the ring, but we should perform these replacements in an orderly fashion based on accumulated experience as well as vigorous R&D efforts into improved mechanical support, thermal stress alleviation, and figure accuracy.

Estimated costs of optics R&D and upgrades (in FY'06 dollars): 2.25M$/year

8.2. Detectors

Available detectors are not well-matched to the capabilities of the ALS and other high-brightness synchrotron radiation sources. There is need for a broad-based program to benefit the community, based in part on high-energy-physics detector developments, to create high-rate pixel detectors. In addition, high-speed streak cameras are needed to fully utilize the femtosecond sources coming online. The ALS, in cooperation with the LBNL Engineering Division, has started work in these areas. Because of its importance to our user program, we plan to expand detector development and bring it to successful conclusion via technology transfer to a commercial supplier.

Estimated costs of detector R&D (in FY'06 dollars): $1.5M/year

THE HUMAN DIMENSION

9. Safety First

The safe operation of the facility and the user program is the top priority of both ALS management and the ALS community. As the user community grows and the experimental floor becomes more crowded, maintaining and further improving our excellent safety record becomes an ever-increasing challenge. We will continue and enhance the safety training of staff and users alike. We will hire and redeploy staff to increase overall safety.

10. Infrastructure and User Support

To maintain and further improve the position of the ALS as the premier user facility for soft x-ray and VUV science, the source and beamline developments described above are necessary, but not sufficient. The ALS needs to create an even safer, even more user-friendly and supportive environment.

10.1. Beamline Staffing

The staffing level of most of the beamlines is barely half of what is considered optimal. Our remarkably talented and dedicated staff members are stretched thin and are heavily overloaded. It is a general observation that staffing levels go hand-in-hand with scientific productivity, and hence the facility is significantly underutilized. The intellectual excitement of the ALS as a forefront science facility has been a powerful tool in the recruitment and retention of outstanding staff, but additional sustained efforts are required to increase diversity both in gender and in underrepresented groups. We continue to seek support to increase beamline staff so as to optimize utilization of the facility.

10.2. User Support Building

Both safety and productivity are jeopardized when crowding becomes extreme, when there is inadequate lab and office space available to support the program. LBNL has proposed and designed a User Support Building to relieve this serious situation. This is a very high priority for the ALS, with line-item funding proposed in the President's FY07 budget.

10.3. User Guest House

As with any user facility that operates around the clock, providing adequate housing and meal service to users is essential. The current arrangement (provision of leased ALS apartments) does not satisfy the need, as there is not enough capacity, and the location is quite noisy. LBNL plans to construct a Guest House within walking distance of the ALS and the LBNL cafeteria. The building will be built and run by private contractors, with the cost recovered from rental fees.

10.4. Education and Visitor Program

To build a more diverse scientific staff, the ALS has to contribute to the "pipeline" of qualified applicants. The ALS Doctoral Fellowship Program, initiated about five years ago, has been very successful in attracting graduate students for carrying out doctoral research in synchrotron radiation science and providing them with a high level of technical training. We intend to expand this program with special emphasis on underrepresented groups. ALS also envisions starting a distinguished postdoctoral fellowship program with the same emphasis, to increase and diversify our pool of candidates for beamline scientist positions.

The Doctoral Fellowship Program also provides a novel and cost-effective way to train the next generation of theorists to work with facility scientists, as well as to engage thesis advisors free of charge. It will also assure a healthy turnover in the talent pool.

The ALS will continue to provide a stimulating environment for visiting scientists. Attracting students to work part- or full-time during the summer will continue to be a high priority. These students actively participate in ongoing projects with beamline scientists and thus get hands-on experience and training. In return they provide valuable assistance to our beamline scientists.

APPENDIX: Workshops and Meetings on Strategic Planning

Spring 2004 Retreats with ALS Staff
1. Electronic Structure and Magnetism, February 17, 2004
2. Materials and Earth Sciences, March 29, 2004
3. Gas Phase, Dynamics and Nanoimaging, April 5, 2004

ALS–UEC Retreat, June 9–10, 2004

ALS Photoemission Crosscutting Workshop, July 29–30, 2004

SAC meeting, December 2004

Users' Meeting Workshops, October 2004
1. Actinide Spectroscopy at the ALS
2. Advances in Crystallographic Data Analysis and Acquisition
3. Magnetic Nanostructures, Interfaces, and New Materials: Theory, Experiment, and Application
4. Nanoscience at Synchrotrons
5. New Complex Materials for Synchrotron Science
6. New Directions in Hard X-Ray Microspectroscopy and Spectromicroscopy
7. Photon-In and Photon-Out X-Ray Spectroscopy in Material Sciences, Environmental Energy, and Chemical Analysis
8. X-Ray Microscopy: Advances and Challenges
9. What's Behind the Shielding? An ALS Accelerator Tutorial
10. Modern Valence Band Photoemission Spectroscopy: The Legacy of W.E. Spicer and a Powerful Tool for Materials (Joint ALS–SSRL workshop at SSRL)

SAC meeting, July 2005

Wave 1 workshops COSMIC, May 2005 Soft X-ray Scattering, September 2005

Users' Meeting Workshops, October 2005
1. An Introduction to Synchrotron Experimental Techniques
2. Forefront AMO Science: Clusters, Ions, Dressed States...
3. Frontiers of Synchrotron-Based X-Ray Microdiffraction
4. New Visions in Bandmapping
5. Macromolecular Crystallography I: Advanced Experimental Techniques for Getting the Best Data from Difficult Samples
6. Macromolecular Crystallography II: New Strategies for Data Processing with Automated Software Tools
7. Novel Approaches to Soft X-Ray Spectroscopy: Scanning Transmission X-Ray Microscopy and Ambient-Pressure X-Ray Photoelectron Spectroscopy
8. Soft and Hard X-Ray Tomography at the ALS
9. Soft X-Ray Photon-In and Photon-Out Spectroscopy: New Frontiers
10. THz Science and Technology Network: Opportunities and Organization
11. Ultrafast X-Ray Science at the ALS
12. XANES and EXAFS Spectroscopy of Materials and Biological Samples: Expanding the Range of Applications at Beamline 9.3.1

SAC meeting, December 2005